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Safety evacuation in building engineering design by using BuildingExodus

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Abstract

The crowd motion and the evacuation process in a building engineering design were simulated by BuildingExodus tool when a combustible dust layer fire happened in this building. It focused on the effect of number of exits and population on time of evacuation, and evacuation efficiency of each exit by modeling the building. The simulation results were shown that the evacuation process would become much easier with the increase of exits and decrease of population. It was found that there was a linear relationship between number of population and time of evacuation. In the case study, the maximum allowable number of population was 2970. The evacuation efficiency of WN-1ST, FS2_1ST and DOOR7 was far better than FS_1ST and ES_1ST

Keywords: Building engineering; dust layer; fire; safety evacuation; simulation

1. Introduction

Development of building spaces with increasingly larger and more geometrically complex areas were rapid recently in China. These types of building include teaching& laboratory building, department stores, and concert venues, and are always crowded with people especially in the holidays or active days [1]. However, accidents such as fire, toxic gas release and so on, always threaten human lives in these buildings. If the crowd fails to escape from a building in time, due to failure of obstacles' avoidance or wrong exit selection, people may be injured and killed **[2].**

Several big fires had happened in these large buildings in China. For example, a big fire occurred in Zhongshan, Guangdong, China on 25 December 2005, losing 26 lives and causing 11 injuries [3]. Therefore, safety evacuation of a group of pedestrians from the hazardous areas is still a major issue. In a certain building, due to the absence of data from real evacuations, a suitable modeling or simulation method may be required in order to analyse how the complexities of the building layout may effect a potential evacuation of the occupants [4-6]. After that, some measures can be taken to evacuate people from the danger zone through exits within the shortest possible time, and to help evacuation missions to be carried out efficiently and effectively [6-8].

Since building fire accidents in the college happened frequently in recent years, the aim of present work is to study safety evacuation under the condition of combustion of dust layer in a certain teaching- Lab building by using BuildingExodus tool. It focused on the effect of number of exits and people within the building on the time of evacuation. The simulation can be used for the design on building fire protection and prevention, or safety

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management of such buildings.

2. Simulation tool

Nowadays, more than 22 computer programs for modeling crowd motion and the evacuation process are designed, such as EXIT89, EXODUS, EGRESS, SIMULEX and so on [4,9]. Gwynne et al. [5] made a critical review of the capabilities of 22 different simulation models.

BuildingEXODUS is developed by fire safety engineering group in the University of Greenwich, and is a suite of software tools designed to simulate the evacuation of large numbers of people from a variety of enclosures. BuildingEXODUS codes take into consideration people- people, people- fire and people- structure interactions. As a group of pedestrians make their way out of the enclosure, or are overcome by fire hazards such as heat, smoke and toxic gases, the model can track the trajectory of each individual. The buildingEXODUS model comprises five core interacting sub-models, which are the Occupant, Movement, Behavior, Toxicity and Hazard sub-models. The progressive motion and behavior of each individual was determined by a set of heuristics or rules [9]. In a whole, for a given building configuration, type of occupancy and specific scenario, the tools can provide valuable information for fire specialists in performing fire safety engineering studies.

3. Scenario description

As a case study, a teaching& powder metallurgy Lab was selected for simulation. It was a multi-purpose four-story building whose functions include classroom, laboratory, and test center. The fire resistance classification was second grade. Distribution of eight exits and population in this building was shown in Table 1. It has seven exits in the first floor (Fig. 1，DOOR7 was located at the second floor.). There were large crowds of people which often have many tests in the fourth floor especially at the end of semester. Moreover, some scientific experiments are always conducted in this building, such as dust ignition& flame propagation, powder metallurgy and so on, and they have great hazards of fire & explosion. There 80 percent or more of the population is student, and the other is teacher. The characteristic property and composition of the population was shown in Table 2.

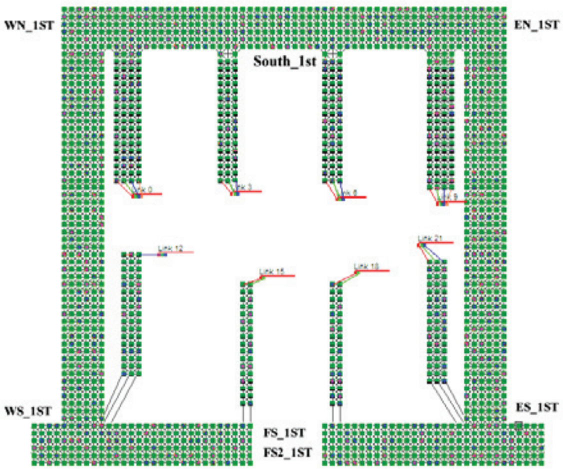
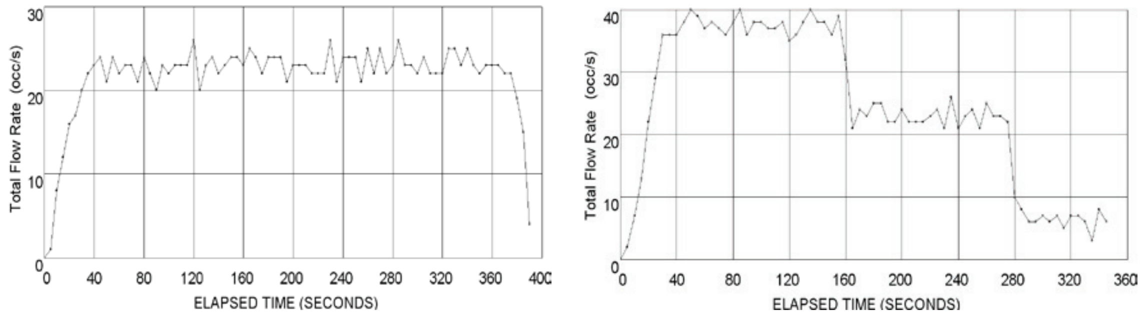
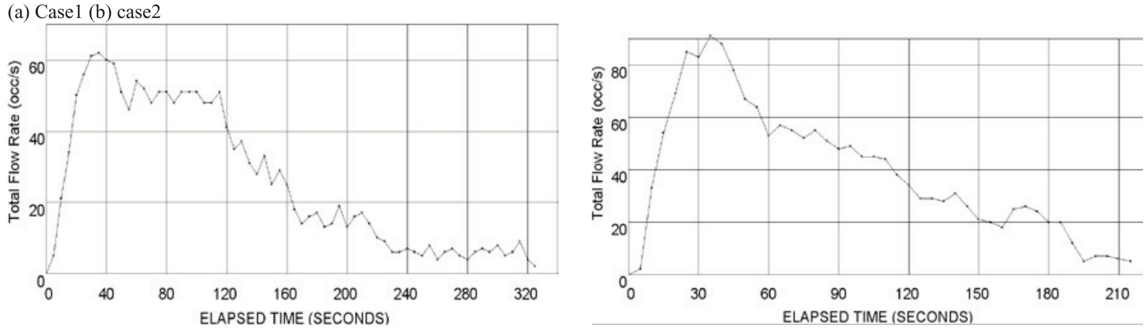


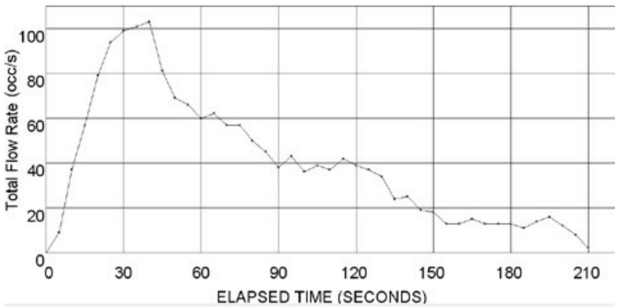
Fig. 4 Construction of the first floor



(a) Case1 (b) case2



(c) Case3 (d) case4



(e) Case 5

Fig. 2 Flow rate in five scenarios

Table 1. Distribution of exits and population in each floor

Floor	population	Exits (Including stairs)	Width of all exits /m	Function of each floor	Description
First	300	7	13	Lab	dust ignition& flame propagation
Second	500	9	9	Classroom, Lab	One direct exit, 8 links to the first and third floor with stairs, powder metallurgy
Third	500	8	7	Classroom, Lab	dust ignition& flame propagation
Fourth	400	6	7	Video arcades, Test Center	There were large crowds of people sometimes

Table 2. Characteristic property and composition of the population

NO	Sex	age	Weight /kg	Height /m	Velocity/ m/s	movability	percent
1	Male	18～22	50～70	1.6～1.9	1.2～1.5	1.0	40%
2	Female	18～22	40～60	1.5～1.7	1.2～1.5	1.0	35%

3	Male	22～30	55～75	1.6～1.9	1.0～1.3	1.0	10%
4	Female	22～30	45～65	1.5～1.7	0.9～1.1	1.0	5%
5	Male	30～50	60～80	1.6～1.8	0.9～1.2	0.9	5%
6	Female	30～50	50～70	1.5～1.7	0.8～1.0	0.9	3%
7	Male	50～65	60～80	1.6～1.7	0.7～0.9	0.8	1.5%
8	Female	50～65	50～60	1.4～1.6	0.7～0.9	0.8	0.5%

4. Simulation

4.1. Effect of number of exits on time of evacuation

When the number of people is 1700, the effect of number of exits on time of evacuation was shown in Table 3.The layout of some couple of exits is geometric symmetry, including WN_1st & EN_1st, WS_1st & ES_1st, and FS_1st & FS2_1st, so each couple of exits was opened or closed simultaneously in the simulation. The results were shown that the number of exits had a great effect on the time of evacuation. The larger the number of exits was, the shorter the time of evacuation was. The time of evacuation 205.88s was satisfied with GB50016 – 2006 (the required time of evacuation is within 300 or 360s in the standard [10]). The flow rate of population was shown in Fig. 2 in such cases. The larger the number of exits was, the larger the maximum flow rate was. The flow rate was 25 occ/s in case 1, and it was 100 occ/s in case 5. It was interesting that the maximum flow rate happened at 40s, whatever the scenario number was. The congestion of population occurred when maximum flow rate arrived. The duration of congestion became longer with the decrease of exits. For example, the time interval of continual congestion is from 40s to 360s in Case 1. The discontinue congestion occurred in Case 2, but no congestion happened in Case 5.

Table 3. Number of exits & time of evacuation

Scenario	Exits	Time of evacuation/ s	Description
Case1	1	386.31	Only door7 opening
Case2	2	343.97	Only door7 and south_1st opening
Case3	4	320.52	door7, south_1st, and WN_1st & EN_1st opening
Case4	6	213.10	door7, south_1st, WN_1st & EN_1st, WS_1ST & ES_1ST opening
Case5	8	205.88	All exits opening

4.2. Effect of number of people on time of evacuation

The numbers of people in special days is twice or triple as much as those in ordinary days, such as date of recruitment, end of semester and so on. The potential pressure of safety evacuation for so much people was very high in these periods. The linear relationship between population and required time of evacuation was shown in Fig. 3, when number of people is 850, 1700, 2550, 3400, 4250 and 5100. When all exits were open for 3400 and 5100 persons, time of evacuation is 410.49s and 609.90s which weren't satisfied with GB50016– 2006. The extra periods were 206.41s and 404.02s in contrast to the one of 1700 persons. The linear fit equation between population and required time of evacuation was presented in Eq. (1).

$$y = 0.115x + 17.095 \tag{1}$$

where y is time of evacuation and x is number of people.

When the required time of evacuation of a certain building is 360s, the allowable maximum number of people calculated by Eq. (1) is 2976. As number of people was 3400 and 5100, the maximum flow rate arrived at 40s (Fig.

4) which is similar with case 5 in Fig. 2. The duration of maximum flow rate increased with the increase of number of people. Therefore, it was important to limit the maximum number of people within the building in special days.

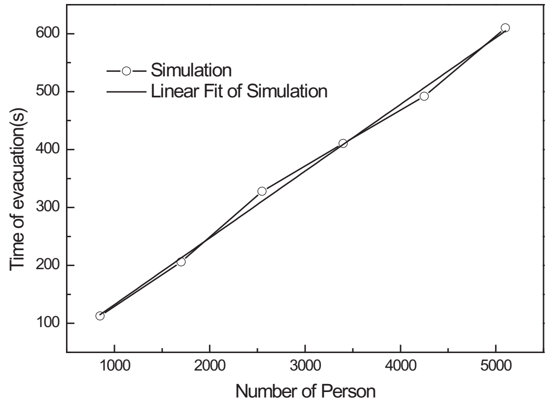
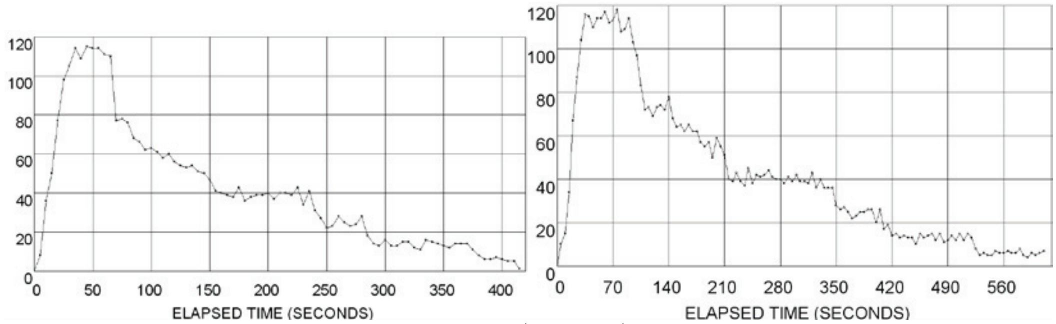


Fig. 3 Relationship between population and required time of evacuation



（a）3400 人 (b)5100 人

Fig. 4 Flow rate in the two scenarios

4.3. Efficiency evaluation of exits

Optimal Performance Statistic (OPS) was usually used to evaluate the whole evacuation efficiency of all exits or to evaluate the balance of evacuation efficiency of each exit in a certain building [11]. The smaller the OPS is, the more similar the evacuation efficiency of each exit is. Mean Non-flow Statistic (MNS) was usually used to evaluate the evacuation efficiency of one certain exit or all exits. The smaller the MNS is, the higher the evacuation efficiency of one certain exit is. In all scenarios mentioned above, the results of OPS and MNS of all exits were shown in Table 4. It was found that the balance of evacuation efficiency of each exit was better in Case 4 than other cases except one extreme case (Case 1). The MNS of each exit in Case 5 was shown in Table 5. The evacuation efficiency of WN-1ST, FS2_1ST and DOOR7 was far better than FS_1ST and ES_1ST.

Table 4. Whole evacuation effieciency of all exits

Scenario	OPS	MNS (%)
Case1	0	0
Case2	0.541	0.155
Case3	0.596	0.125
Case4	0.491	0.0
Case5	0.535	1.0675

Table 5. Evacuation effieciency of each exit in Case 5

Exit	MNS (%)
WN-1ST	0
EN_1ST	0.99
WS_1ST	0.22
FS_1ST	2.63
FS2_1ST	0
ES_1ST	1.99
DOOR7	0

5. Conclusion

(1) The time of evacuation decreased with the increase of number of exits. At the same time, the maximum flow rate increased, and the duration of this flow rate decreased with it.

(2) With the increase of population within the building, the probability and duration of congestion will increase, and then the whole evacuation time would increase linearly. According to the linear relationship between population and evacuation time, the maximum allowable number of people is 2976 in this case study. Otherwise, the evacuation time wouldn't be satisfied with GB50016– 2006. It was wise to limit the maximum of people in special days.

(3) In all scenarios mentioned above, the balance of evacuation efficiency of each exit was better in Case 4 than other cases except the extreme case (Case 1). The evacuation efficiency of WN-1ST, FS2_1ST and DOOR7 was far better than FS_1ST and ES_1ST in Case 5.

(4) The methods by modeling the building are very helpful for the building engineering evacuation design.

Acknowledgements

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